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RAINFALL MAPS OF LATIN AMERICA.

By EUGENE VAN CLEEF.

[Chicago, Ill., May 11, 1921.]

INTRODUCTION.

The accompanying rainfall maps were prepared originally in wall-map size as a part of the work of the Latin American Division of the House Inquiry, New York City, June-December, 1918. The study was made in the building of the American Geographical Society, where this society's splendid library of books and maps was readily available.

The sources of data were numerous, though the data were limited. The various libraries in New York City were consulted. In some instances data were gathered from private libraries of corporations. Individuals who had visited portions of the regions were called upon to to contribute what data they might have gathered and to give of their experiences and observations. The Government libraries in Washington, D. C., were referred to, and many men in the Government scientific departments gave generous aid—both data and criticism of the maps. The circumstances, therefore, under which these maps were constructed were highly favorable. In fact, it would be difficult to reproduce them, excepting under some such urgency as was brought about by the Great War.

The first two questions requiring careful consideration were: (1) On what type of base map should the data be plotted, and (2) how should the data be treated? The first question was the more easily answered. A new hypsometric map of Latin America was in course of preparation which it was planned to use. Unfortunately, work did not progress on this as rapidly as hoped for, and therefore the base of the South America map in the Goode Series was put into service.[1] Maps of Mexico and Central America were adapted from Mexican Government maps.

The second question, relating to data, presented a number of problems. Data for most of the areas are scarce and, with few exceptions, not wholly reliable. The records for most stations are of short term. Furthermore, they are not always for corresponding periods and hence not always comparable. While the data ought to be reduced to a common base, their irregularity in so many respects made this impractical, and so it was decided to plot them without modification, but in the drawing of the isohyets to use the greatest caution, bearing in mind these inaccuracies. Consequently, the drawing of these isohyets resolved itself largely into a matter of interpretation.

Figures alone could not suffice where interpretation plays so large a part. The distribution of the highlands and lowlands, the prevailing winds, the drainage systems, were given considerable weight. Where data on humidity and evaporation were available consideration was given them. The nature and distribution of the vegetation and character of soil were oftentimes used as determining factors. In other words, every piece of evidence that might shed some light on the probable course of the isohyet was brought into play.

It is not supposed that these maps[2] are in any way a final statement of the distribution of rainfall in Latin America. It may require another 75 years or longer before we have enough accumulated data to produce an accurate map. These maps are only intended to serve as a slight contribution to the slowly accumulating knowledge about our neighbors to the south.

In the following paragraphs a brief account is presented descriptive of the rainfall distribution. One of the interesting problems in the determination of this distribution is described as illustrative of numerous problems still to be solved.

RAINFALL IN MEXICO.

The distribution of rainfall in Mexico is controlled by the northeast trades and the extension of the great Hawaiian and Azores high-pressure areas over North America during the winter season, coupled with the presence of north-south mountain ranges of considerable elevation.

In the winter season the high pressure over North America results in a shift of the winds from northeasterly to northerly. These winds, blowing over the continental mass of the United States and northern Mexico, are relatively dry, and hence result in bringing about only minor quantities of rainfall. Occasionally the winds blow from other directions, but at no time are they sufficiently marked to increase the rainfall notably at any given point. As summer approaches, the pressure breaks down over the northern part of North America, and the northeast trades become well defined. As they blow across the warm waters of the Caribbean Sea and the Gulf of Mexico, much moisture is carried inland upon the highlands of Mexico. The result, of course, is fairly heavy precipitation. The seasonal shifting of the winds is quite regular, hence the variation in amount of rainfall

[1] This series of maps is published by Rand McNally & Co., Chicago, who very kindly permitted the use of the base.

[2] The isohyets of Central America, although drawn in full lines, should be considered, at best, as close approximations only. The same may be said of the isohyets for South America, except for certain parts of the South Temperate Zone. Mention should be made of a very recent contribution upon the rainfall of Chile by Prof. Mark Jefferson, *American Geographical Society Research Series*, No. 7, New York, 1921. This publication has appeared since the manuscript of the above article was received.—EDITOR.

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is quite as well clearly marked. In the case of Chihuahua, in northwestern Mexico, the increase from almost nothing during the first half of the year to some 200 mm. during July is noteworthy. This, however, is a pure case of the influence of highlands upon precipitation and local wind conditions. It probably also is affected by the low-pressure areas common in this part of the continent, which carry in a considerable amount of moisture from the Gulf of Mexico. To be sure, it is an indirect process, but nevertheless it is effective. Just what rôle cyclones and anticyclones play in affecting the climatic conditions of northern Mexico is not well understood because of the lack of observations. It seems, however, that this must have a strong influence, in view of the effects in Texas and the other bordering States of the United States.

Records for brief periods of time indicate prevailing winds for scattered points as coming from directions other than those which one would expect in a system of shifting northeast trades. This inclines one to the belief that too much emphasis has been placed upon the influence of northeast trade winds in Mexico, and insufficient upon the likelihood of cyclonic and anticyclonic influences referred to above.

Three characteristic winds along the Pacific coast influence the distribution of rainfall. They have special names. The northers, when sufficiently strong to blow across the plateau lands into the more southwesterly parts of Mexico, and accompanied by clear weather, are called *Papagayos*. Southwest winds, resulting in a rainy season during the summer time, are known as *Temporales*. At the beginning and the ending of the rainy season, well defined thunderstorms of considerable proportions, seemingly coming out of the east, are called *Chubascos*.

RAINFALL IN CENTRAL AMERICA AND PANAMA.

The northeast trades on the Atlantic coast, and the southwesterly winds of the Pacific coast, the latter sometimes said to be a new direction of the southeast trades as they cross the Equator, are the controlling factors in the distribution of rainfall. However, it is essential to call attention to the fact that these winds do not always reach over the land, but are occasionally supplanted by a local circulation which brings about an effect wholly different from that which might be expected from the popularly better-known winds. The trades of the Atlantic coast and the southwesterlies of the Pacific coast are fairly constant over the water bodies. The general conditions for the west coast and the east coast follow.

The west coast.—Along the west coast the dry season occurs from January to March. This is the season of the *papagayos*, or easterly gales. Only occasionally do light showers fall. The season is truly dry. In general, the weather from December to March is quite delightful when the north to northeast winds have effectively counteracted the influence of the southwesterlies, which might be said, in popular terms, to have been driven away from the coast. This dry period is followed by a rainy season called the *Invierno*. This rainy period increases in severity until about June, when it reaches its climax, and is followed in a month or two by a relatively dry season known as the *Veranillo de San Juan*. There again follows an increase in precipitation, not so great as that of the first maximum, after which there is a decided reduction in rainfall or, in other words, a return to the dry season of the first part of the winter. Most of the rainfall occurs in the form of thunderstorms and, therefore, may be said to be an afternoon phenomenon. These thunderstorms are daily and occur with almost clocklike regularity.

East coast.—In contrast with the west coast, there is no real dry season along the east coast, although the curves for stations along the east coast would seem to show a distinct dry season. The dry season, however, is only relative, that is, it rains less at one time of the year than at another. There are two such depressions during the year: One in the springtime, and one, much shorter and less well marked, in the late summer and early fall. During the northeast trades from October to about January, the rains are almost continuous. A second rainy season occurs from June to August. The first relatively dry season occurs from February to April, while the one less well marked makes its appearance rather uncertainly during a late summer or early fall month, such as August, September, or early October.

The division of the year into two rainy periods and two dry periods is not only characteristic of the territory extending from southern Mexico to Colombia in South America, but is equally true for practically all of the West Indies.

RAINFALL IN SOUTH AMERICA.

The distribution of rainfall in South America is a factor of the distribution of highlands, lowlands, and water bodies, versus atmospheric circulation. The shifting of wind systems produces a variation in the amount of precipitation in the several regions of South America, as noted in detail below:

The rainfall areas of South America impress one with their symmetry, corresponding to that of the distribution of highlands and lowlands.

South America may be readily divided into certain rainfall provinces:

(1) A wet northwest Pacific slope.
(2) A dry central Pacific slope.
(3) A wet south Pacific slope.
(4) A wet northern interior.
(5) An intermediate southeast interior and coastal region.
(6) A local Brazilian highland dry region.

These six areas may be defined roughly as follows:

(1) The slope of the Andes, extending from the Isthmus of Panama to latitude 4° south.

(2) The western slope of the Andes, from latitude 4° south to 36° south. This zone extends over the crest of the Andes in latitude above 30° south, and continues along the eastern slope through Patagonia to the Atlantic coast,

(3) Latitude 35° south to Cape Horn.

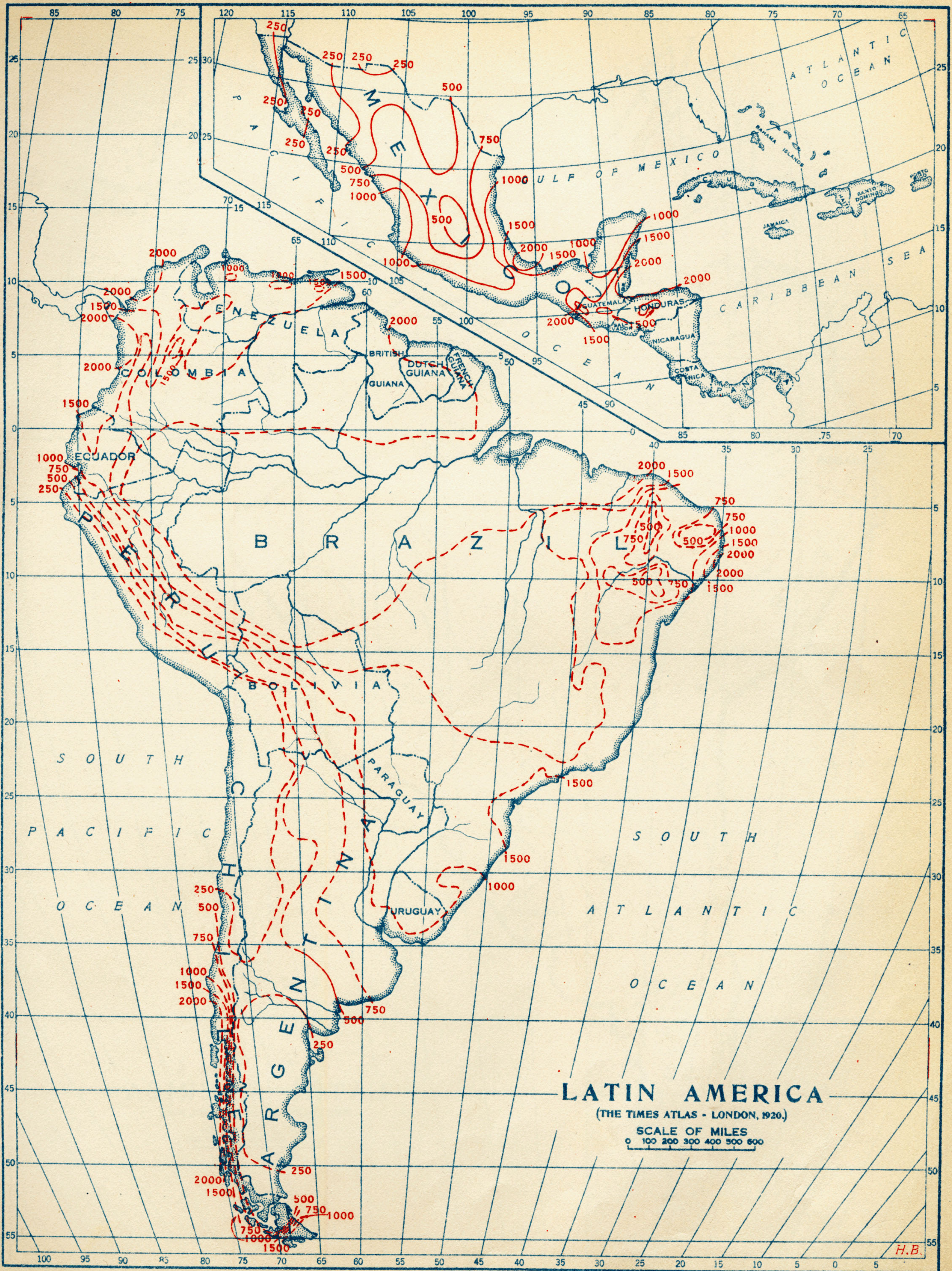
(4) Essentially the Amazon River Basin.

(5) The Gran Chaco, Paraguay, Uruguay, northern Argentine region.

(6) Three islands of diminished precipitation in the States of Ceara, Rio Grande Do Norte and in extreme northwestern Bahia, extending across the Rio Sao Francisco into Pernambuco as shown on the chart of annual precipitation.[3]

It is perhaps worth while to note the characteristics of the shifting winds as affecting the increase or decrease of rainfall in these regions. The heavy rainfall in region (1) is due to the prevailing southerly to southwesterly winds, occurring during essentially each month of the

[3] The author's rainfall maps, with his consent, were submitted to Director Sampaio Ferraz of the new Brazilian Meteorological Service, during his recent visit to the central office of the Weather Bureau. Director Ferraz volunteered to supply data for northeastern Brazil, evidently not available to the author. These data have been furnished and the isohyets of the original chart of annual rainfall have been modified accordingly. The charts of winter and summer precipitation are, however, as presented by the author.—EDITOR.


LATIN AMERICA
(THE TIMES ATLAS - LONDON, 1920.)
SCALE OF MILES
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ATLANTIC OCEAN
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CARIBBEAN SEA
PACIFIC OCEAN
MEXICO
CUBA
JAMAICA
BAHAMA ISLANDS
SANTO DOMINGO
PORTO RICO
GUATEMALA
HONDURAS
NICARAGUA
COSTA RICA
PANAMA
VENEZUELA
COLOMBIA
BRITISH GUIANA
DUTCH GUIANA
FRENCH GUIANA
ECUADOR
PERU
BRAZIL
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PARAGUAY
CHILE
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URUGUAY
SOUTH PACIFIC OCEAN
SOUTH ATLANTIC OCEAN
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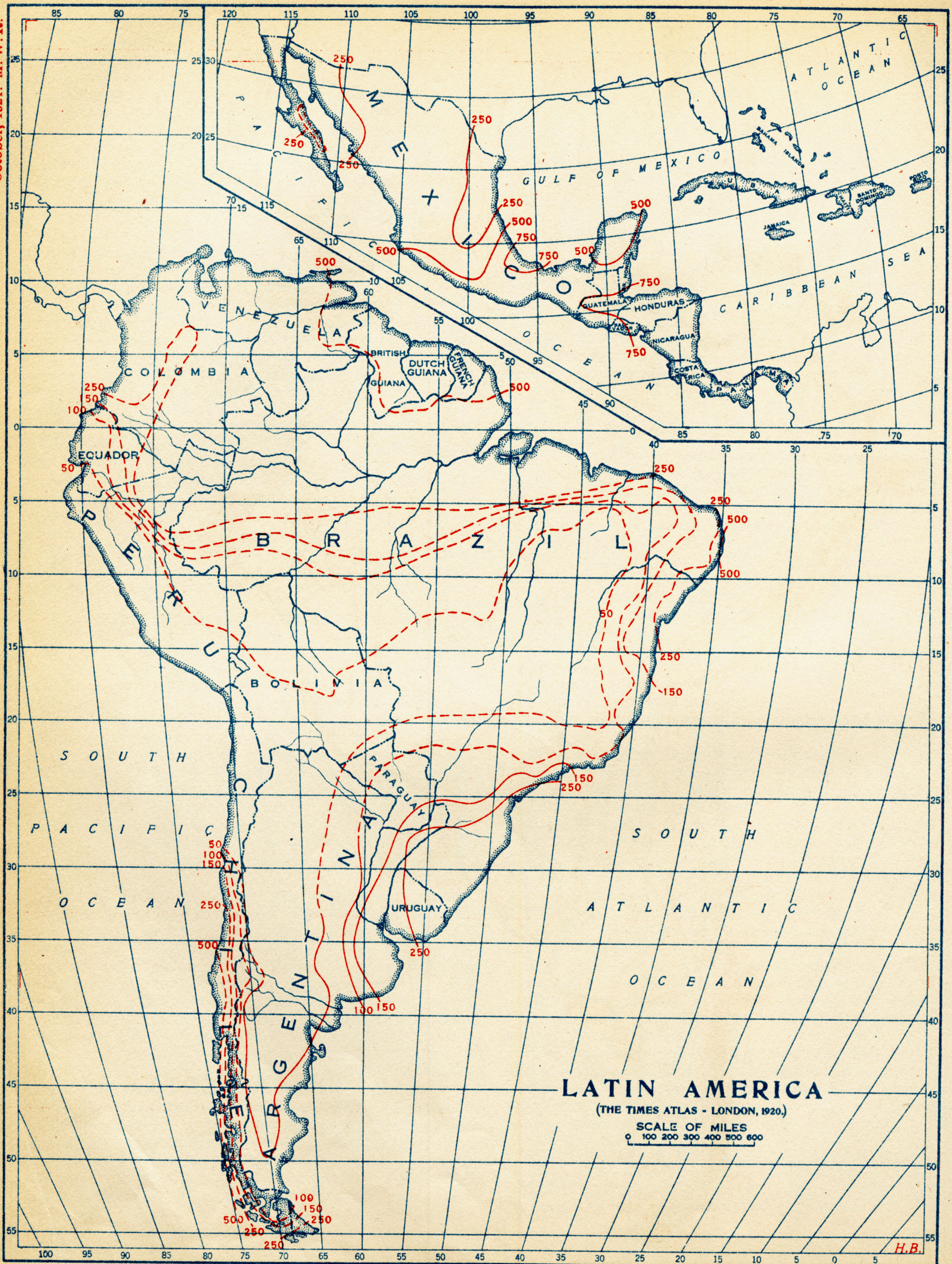
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BAHAMA ISLANDS
JAMAICA
SANTO DOMINGO
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GUATEMALA
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COLOMBIA
BRITISH GUIANA
DUTCH GUIANA
FRENCH GUIANA
ECUADOR
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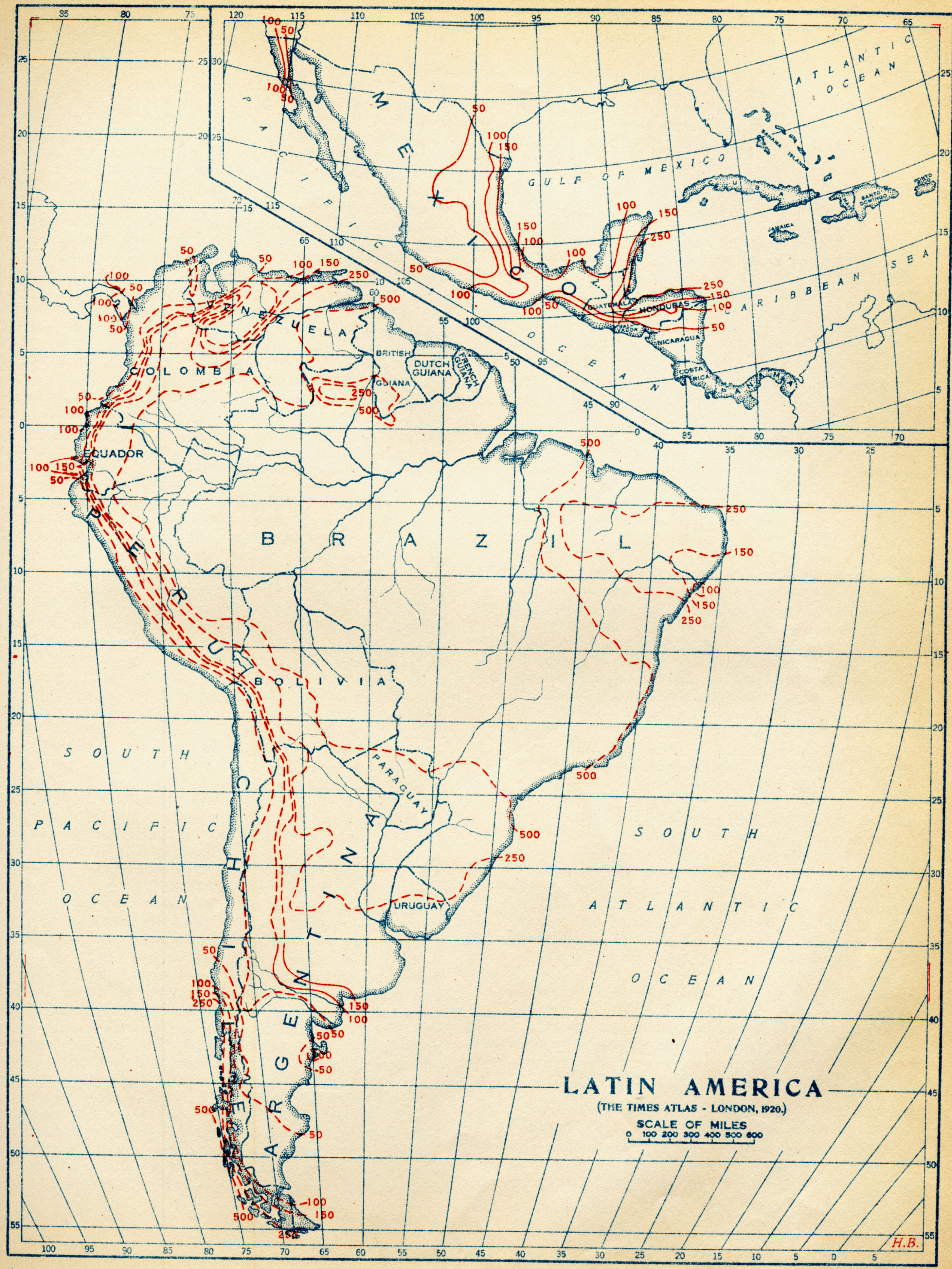
LATIN AMERICA
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SCALE OF MILES
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COSTA RICA
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PARAGUAY
CHILE
ARGENTINA
URUGUAY
SOUTH PACIFIC OCEAN
SOUTH ATLANTIC OCEAN
H.B.

year, due to the probable influence of the permanent South Pacific high-pressure area and a strong sea breeze. These southwesterly winds, blowing across the Pacific upon a highland slope, are diverted upward and depleted of their moisture as their temperature is lowered. It should be noted here that the influence of the South Pacific HIGH is dominant immediately along the west coast of South America, because of the cold currents in the ocean. These currents cause a considerable difference in temperature between the air over the water and that over the coast, giving rise to a landward movement of the air. The rainfall in region (2) is strikingly small; in fact, the region is a desert. Along this part of the coast, the winds from the South Pacific HIGH parallel the coast, producing essentially no effect upon it, while the prevailing southeasterly trades lose their moisture as they rise over the crest of the Andes and descend on the Pacific slope. These winds, descending from great heights, become evaporating rather than precipitating winds, and so intensify the aridity of the coastal strip over which they blow. This statement holds true as far south as latitude 30° to 32°. Beyond this latitude, where the desert area laps over into Patagonia, the belt of prevailing westerlies is encountered. As these winds pass over the Andes and descend the eastern slope, they play the same rôle which the southeasterlies played above. In region (3) the prevailing westerlies blowing from the Pacific are heavily laden with moisture. As they rise over the slopes of the Andes their moisture is condensed, resulting in heavy precipitation upon the windward coast. In region (4) the doldrums control the situation. These winds, consisting of warm, rising air, precipitate their moisture in the area over which they rise when reaching high altitudes. Since the air currents are essentially all vertical, and the temperatures at the surface are relatively high, the alternating processes of evaporation and precipitation result in a heavy rainfall for the entire basin. The area, which is rather extensive, is influenced by the southeast and northeast trades, respectively, as the wind belts shift southward and northward. As a consequence, on the outer borders of the doldrums there are two rainy seasons. In the region of the Guianas, the doldrums are effective in June.[4] At the same time, the southeasterly trades have moved northward to approximately the latitude of the Equator and increased the amount of precipitation over the southern Brazil and northern Paraguay. As the doldrums shift southward during the next six months, a short dry period intervenes in the Guianas, followed by another wet period due to the more southerly extension of the northeasterly trades. During this same period, the southeast trades have moved farther southward, resulting in a dry season for southern Brazil and northern Paraguay. The next year the process is repeated. Throughout the entire year, however, the doldrums are effective in the immediate vicinity of the Equator and east of the Andes highlands, causing only a slight variation in the amount of rainfall, a little more between the Equator and about 8° north during June, a little less between the Equator and about 8° south during the following December.

In region (5), where the rainfall is intermediate, the principal factor is the southeasterly trades. There results an alternating dry-and-wet period, the dry period occurring in December when the southeasterly trades are farther south, and the wet period in June when they are farthest north.[4] The flatness of the land permits these winds to penetrate far inland and distribute their moisture rather evenly instead of in concentrated form at any particular point, with a possible exception of limited areas along the coast in the latitude 23½° south. The explanation for the semiarid regions in northeastern Brazil (6), is not available. Theories have been offered, but are not sufficiently well founded to warrant their acceptance.

[4] June and December are mentioned as representative of winter and summer seasons, respectively.

THE PROBLEM OF THE LLANOS OF COLOMBIA AND VENEZUELA.

Exact data for the region are not available. Descriptions by a few explorers of sections of the territory give some light. The most striking feature, which to date has had no satisfactory explanation, is the treeless character of the interstream area. These regions are occupied by tall grasses, mostly succulent, while the banks of the numerous rivers which drain the land are lined with a dense forested growth. Away from the rivers the vegetation occasionally shows xerophytic characteristics.[5]

In the absence of figures the distribution of precipitation throughout the year can only be described more or less hypothetically. The year is characterized by two seasons, a wet and a dry, with the dry season perhaps slightly longer than the wet. The rainfall during the dry season ranges perhaps from 50 to 250 millimeters and for the wet season from 250 to 500 millimeters, totaling for the year in the neighborhood of 1,000 to 1,200 mm. The last figures include the rain of the transition months from wet to dry and dry to wet. This distribution in itself might account for the nature of the vegetation. On the other hand, excessive porosity of the soil could constitute the dominant factor in the development of the same floral scene. The absence of trees could hardly be credited to native infertility of the soil. The soil should be highly fertile, since it is derived largely from the Cordillera Oriental, an igneous highland.

It is possible that the paucity of trees is the response to a combination of highly porous soils and an extended dry season.[6] Hettner describes the absence of trees in the upper Magdalena to the high porosity of soils. Since the soils of the llanos must have somewhat similar origin, it becomes quite possible their porosity plays a significant part.

The dry season is sufficiently long, evidently, to make the vegetation dry enough for burning, for the area is burned over quite frequently. If ever there were trees, the burning over annually would in itself soon prove a permanent check to tree growth. The removal of the forest might induce an increased rate of evaporation and therefore tend to check precipitation locally. Burning also reduces the soil fertility after the succeeding third or fourth years when the soil becomes decidedly acid.[7]

The absence of trees, then, may or may not be an index of low precipitation or even of a long drought period. Precipitation might be of very appreciable quantities even during the dry season and yet allow of

[5] The general description here given is derived primarily from the following sources:
Bingham, H.: Journal of an expedition across Venezuela and Colombia, 1906–7. New Haven, 1909.
Hettner, A.: Die Kordillere von Bogota: *Petermann's Mitteilungen*, Ergänzungsheft XXII, 1892.
Rice, Hamilton: *Geog. Jour.*, vol. XXI, pp. 401–418, 1903; vol. XXXV, pp. 682–700, 1910; vol. XLIV, pp. 137–168, 1914.
Chapman, Frank M.: The distribution of plant life in Colombia: *Am. Mus. Natl. Hist. Bull.* XXXVI, 1917.

[6] See note 1, *supra*.

[7] The question of soil acidity resulting from burning over, is still considered unsettled in the United States. In northern and northwestern Germany where burning over has been the customary spring or fall practice, the Government (in 1913) prohibited it. The results of investigation by agricultural experiment stations show that the fertility is increased for only from 1 to 3 or 4 years, after which a period of 25 years must elapse before the original fertility returns.

burning. Only a few weeks of dry weather, with the sun well in the zenith, and hence its rays essentially vertical, are sufficient to make the grasses dry enough for ready combustion. In northeastern Minnesota, where the annual precipitation is about the same as that in the llanos, namely, 750 to 1,000 mm., the rainy season occurs during the summer months, with a primary maximum in June and secondary maximum in September. Yet during late October and November forest and prairie fires are not uncommon. It is true that the pine trees invite fire, but the grasses are probably as succulent as those of the llanos and even these burn readily after a short dry season.

The vegetation of the llanos, therefore, throws little light on the amount of rainfall, and the amount of rainfall so far as it is known does not in itself seem to account for the vegetation. For the present, and until observations through a series of years become available, the assumption remains that the rainfall of the dry season is due to the moisture carried inland by the northeast trades, encouraged as it were, to penetrate so considerable a distance, by the trough formed between the Cordillera Oriental and the Guiana highlands, combined with local excessive heating which induces a lower pressure than that existing to the northeastward of the area. The wet season results from a northerly extension of the doldrums during June, July, and August. These, however, are probably not so effective as farther south, owing to the intensity of local convection, which may be sufficient to carry moisture to elevations of over 15,000 feet where strong westerly winds of the upper air circulation can carry the water vapor away before condensation is accomplished.

No mention is made in the literature, of a local mountain wind from the Cordillera Oriental corresponding to the chinook of North America or the bora of the Adriatic. It seems possible that a local wind resulting from differences in temperature between the crests of mountains and the plains below might develop during the doldrum period, when convection is strong over the plains. An accumulation of cold air on the mountains in sufficient masses could gain large momentum moving down the rather steep slopes and develop into evaporating winds of consequence. This would tend to counteract some of the precipitation which normally should fall in quantity under the doldrum influence. Further exploration of the area might reveal the presence of such winds.

The question, then, of the cause of the apparent dryness of the llanos and the absence of trees in interstream areas must remain in the hypothetical stage. The statements here offered are presented as suggestions and possible bases for further inquiry.

SOME ILLUSTRATIVE TYPES OF LATIN-AMERICAN RAINFALL.[1]

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By BERNARD O. WEITZ.

[Washington, D. C., Nov. 15, 1921.]

SYNOPSIS.

The following is a discussion of a few graphs showing the monthly distribution of rainfall at selected stations in Latin America. These have been grouped as follows:

1. Mexico, Central America, and the West Indies.
2. Western coast of South America (3 sections).
3. Northeastern South America and the basin of the Amazon.
4. Eastern South America, Brazil, Argentina, Paraguay, and Uruguay.

INTRODUCTION.

The accompanying graphs were prepared to supplement Van Cleef's rainfall maps published in this REVIEW. It is of interest to note the effects of the precipitation controls of Latin America, not only on the annual and seasonal distribution of rainfall, but also the precipitation from month to month.

Twenty-five representative stations[2] were selected, embracing the various types of rainfall found throughout the region. The effects of prevailing winds, shifting wind belts, mountains, and ocean currents is to produce a diversity of rainfall types. When we correlate the geographic coordinates of various localities with the climatic controls mentioned above, the explanation of the different types usually becomes apparent. The characteristic distribution and climatic factors affecting these types are discussed.

Mexico, Central America, and the West Indies.—Over this entire area the most important of the precipitation controls is the northeast trade, with its characteristic winter maximum on windward coasts and mountains. The southern part, however, especially the leeward shores (cf. Panama), is subject to the midsummer convectional rains accompanying the northern position of the heat equator belt of calms (doldrums).

In most of Mexico the annual minimum comes during the winter and early spring, the region being too far south to be affected much by the southern extensions of strong extra-tropical LOWS. The maximum comes late in summer, the moisture for these convectional rains coming from the Gulf of Mexico. Mexican rainfall may be described as the marginal tropical type, the trade-belt rains being affected[3] by the migration of the equatorial rain belt with the northward and southward movement of the sun. During this time the trades seem to strike the windward coast from a more easterly direction than during the winter, when they blow from the northeast and have a drying influence.

In the West Indies the principal control is the northeast trade. Owing to the east-west trend of the mountains in Cuba, Santo Domingo, and Porto Rico, the northern and eastern coasts are much moister than the southern coasts, and the monthly distribution on the windward side of the mountains is also more equable than on the lee side. The minimum occurs in February, with another secondary minimum in midsummer, when the trades are weakest.

Over the Isthmus of Panama rains are fairly heavy.[4] Here we again find, considering the Canal Zone as a whole, two annual rainfall maxima, one in May and the second in October. The seasonal minimum occurs during the first three months, March usually being the driest month. The rains are, to a large extent, convective,[5] thunderstorms being frequent, especially over the Isth-

[1] The preparation of this paper was begun in connection with a course in "Climates of the World" conducted by Prof. C. F. Brooks, at Clark University Summer School 1921.

[2] In order to get the longest normals conveniently available, the following were referred to:
(a) Hann's *Handbuch der Klimatologie*, Stuttgart, 1908-1911, vols. 2 and 3.
(b) Voss: *Niederschlagsverhältnisse von Südamerika, Petermanns Mitteilungen*, Gotha, 1907.
It is recognized that the averages given are in some cases based on short records, but it is obvious that the essential characteristics of longer records, with respect to seasonal distribution of rainfall, would be the same.

[3] R. DeC. Ward, *Climate*, G. P. Putnam's Sons, 1908-1918, pp. 84-85.

[4] F. D. Willson, The climatology and hydrology of the Panama Canal, *Proceedings International Engineering Congress*, San Francisco, Calif., Sept. 20-25, 1915.

[5] H. G. Cornthwaite, Panama rainfall, MONTHLY WEATHER REVIEW, May, 1919, 47: 298-302.